THE WORLD OF CHEMISTRY

Program #5

A MATTER OF STATE

Producer Doug Bolin

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

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Annenberg/CPB Project Logo and Music

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MONTAGE: The natural world

NARRATOR (MUSIC and NAT SOUND under):
There is a mystery to this world around us, an idea so obvious we take it for granted, but so important that all chemistry starts from it. Everything in our world exists in one of three states, as a gas, a liquid, or a solid, but can change from one state to another. How is this possible? What happens as a solid becomes a liquid and a liquid a gas? In the world of chemistry, it's all a matter of state.

SUPER: A MATTER OF STATE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH next to Potomac River

ROALD HOFFMANN (SYNC):
The Great Falls of the Potomac River, near Washington. Everything in the scene around me, the rocks, the flowing water, the trees on the other side, even the air that I breathe, everything is matter, it's chemical. And even though we see hundreds of different substances, millions were I to look with a microscope, these substances fall into certain groups or classes that we can identify as gases, liquids, and solids. These are the states of matter. Gases are tenuous, compressible. The space that matter fills -- we call that volume -- is obviously occupied less densely in gases than it is in the other states of matter. Liquids are fluid, deformable, more dense than gases. And solids are more compact still, often denser. And it's not only that the states are there. We, or nature, can change them.

MONTAGE: Shots of crystals, lava, streams, balloons, clouds

NARRATOR (MUSIC and NAT SOUND under):
Why is a crystal like an iceberg? How is lava like a stream? What does a balloon have in common with the air around it? The iceberg and the crystal are both in the solid state. (cont.)

NARRATOR cont:
This lava and the water in the stream are both in the liquid state. The matter inside this balloon and the air around it are both in the gaseous state. Under certain conditions, matter changes state. What makes this transformation possible? Water at one temperature is a liquid, at another temperature a gas, at still another, it is a solid. If we are to begin unraveling the secret of matter's transformation, temperature is a clue. What is its effect on liquids and gases?

DS in lab

DON SHOWALTER (SYNC):
Let's start out by looking at the effect temperature has on pressure. What I'm going to do is heat this pan. This is a rigid pan, has some water in the bottom of it. Now, as the water is heated, it will change state. You're very familiar with the term steam, huh? Steam, now, is gaseous water. Now, as that steam is formed from that liquid, liquid to gas, it will drive out the air that was inside that can, and, hopefully, we'll be able to see some of the steam that is coming out of the top of the can. Once we have driven all the air out, what I'm going to do is put the top on there, and we'll let the can cool and see what happens with the pressure as the temperature decreases. What do you think? (cont.)

DON SHOWALTER cont:
Do you think there's enough steam coming out of there to indicate that the, all the air has been driven out? We'll take the burner off, turn that off, we'll cap this up. All right. Now, as the temperature decreases, the can cools, that steam will change back into liquid. As it does that, it will decrease the pressure inside the can. Oh, do you hear that? As the pressure decreases, what, anything happen out here? The atmospheric pressure didn't change. It's pushing on the can just like it was before, but since the pressure is less, as we decrease the temperature the pressure decreases, the can starts to cave in. There it goes. Now look at the can. Notice how the can is crushing. The reason now, again, is because of that atmospheric pressure, the gas of the atmosphere. Inside now, the pressure was reduced because the steam condensed into that liquid, leaving a decreased pressure inside. The atmospheric pressure pushed in the can.

MONTAGE: shots of steam, natural geysers

NARRATOR (NAT SOUND under):
So heating a liquid can change its state to a gas, and there appears to be a relationship between the pressure of matter in the gaseous state and its temperature. But what is the nature of this relationship?

DS in lab

DON SHOWALTER (SYNC):
We'll use this apparatus to try to understand that relationship between the temperature and the pressure of a gas. We have a rigid container here. This is a steel ball that is attached to this pressure gauge. Now, because it's rigid, the amount of gas inside and the volume of the gas will remain the same. The only things we'll vary are pressure and temperature. Let's try it and see what happens. All right. We'll heat it up, using this burner. So as we increase the temperature of the gas inside the ball, what happens to the pressure? Can you see that pressure, what's happening there? It's increasing, isn't it, the number is getting higher? So, as we increase the temperature of a gas, we also increase the pressure. Alright. Now, what would happen if we take the heat away and cool it? Let's see. I'll take the burner away and we'll turn off the gas, and we'll let it cool. It's not cooling fast enough. Let me help it. I've got this ice water bath. I'll stick the ice water bath up there, and we'll cool the ball, and look what happens now to the pressure. As the temperature decreases, the pressure of a gas also decreases. So we see the relationship between the temperature and the pressure of a gas.

Close ups of equipment from DS demonstration

NARRATOR (NAT SOUND under): What is happening to the submicroscopic particles of a gas as they are heated and cooled? How does this affect pressure?

GRAPHIC: Kinetic energy of particles

NARRATOR (MUSIC under): If we could slow down the gas particles and focus on just a few of them, they would look like this, far apart, moving randomly, in straight lines. When they collide with the walls of the container, they exert a pressure against the walls. These moving particles possess kinetic energy. Their speed depends on their temperature. As the gas is heated and the particles move faster, they collide with the walls of the container more frequently. Because they are moving at greater speed, they also strike the walls with greater force. Both effects, the greater number of collisions and the greater force of the collisions, contribute to the increase in the pressure of the gas when the temperature is increased. Cooling a gas decreases the speed of the particles. As the temperature is decreased, the kinetic energy of the particles decreases. They slow down. They strike the walls less frequently and with less force. As we cool a gas down to a certain point, we continue to decrease its pressure.

Close up of lab demo

NARRATOR (NAT SOUND under):
But if we cool a gas beyond that point, something dramatic happens.

Clouds, lightning, rain

NARRATOR (MUSIC and NAT SOUND under):
The gas changes state, to become a liquid. The fact that gaseous matter becomes liquid matter at a low enough temperature is important to us. Every year we use billions of liters of different gases.

MONTAGE: Hospital shots, soft drink factory assembly line, scuba divers, computer chips, oil platform

NARRATOR (MUSIC and NAT SOUND under):
In hospitals, pure oxygen helps very ill patients breathe more easily. In soft drink factories, another gas, carbon dioxide, gives beverages their fizz. Just plain air, a mixture of mostly nitrogen and oxygen, is bottled under high pressure for scuba divers to breathe underwater. Gases are also used in the manufacture of integrated circuits, the processing of steel, the recovery of oil, and many other places.

People cooking with gas,
LNG trucks

NARRATOR (MUSIC and NAT SOUND under):
But the place we are probably most familiar with is the home, where we heat and cook with a gas called methane or natural gas. And we would have a hard time using natural gas if we couldn't liquefy it at low enough temperatures. Lynwood Bazemore is Chief of Baltimore Gas and Electric's Liquid Natural Gas Facility.

INTERVIEW: Lynwood Bazemore, Chief of Baltimore Gas and Electric's Liquid Natural Gas Facility

SUPER: Lynwood Bazemore

LYNWOOD BAZEMORE (SYNC):
The primary reason for liquefying natural gas is to give us added storage capacity. Capabilities of storing LNG are much greater as a liquid than as a gas. To demonstrate, methane, liquefied, is reduced in volume over 600 times. We liquefy during the summer, when our system demands are low. That gas is made available then for storage. And in the winter months, when the demand is high, we can supplement our supplies with our own LNG.

LNG plant

NARRATOR (MUSIC and NAT SOUND under):
Natural gas is converted to a liquid and stored at plants like this throughout the world. Liquefaction is a three-step process. The gas comes in through pipelines in a gaseous state. But it contains impurities, like water vapor and carbon dioxide. So the first step is to cool the gas enough to freeze out the water vapor. This is done in towers that are filled with coils of a cold liquid similar to antifreeze. As the natural gas passes over them, water vapor condenses and forms ice. The natural gas then goes to a filter system that removes other impurities. Now the gas is ready to be chilled to a liquid.

INTERVIEW: Lynwood Bazemore (cont.)

LYNWOOD BAZEMORE (SYNC):
The liquefaction process simply reduces molecular motion. That provides for the condensing of the material. When we remove the sensible and latent heat from the methane from 60 degrees Fahrenheit down to minus-260, molecular motion is essentially slowed down.

LNG plant

NARRATOR (MUSIC and NAT SOUND under):
The red tanks in this plant contain natural gas that is waiting to be liquefied. The white tanks contain liquefied natural gas. The volume occupied by natural gas in the liquid state is so reduced that one white tank can hold 125 red tanks.

INTERVIEW: Lynwood Bazemore (cont.)

LYNWOOD BAZEMORE (SYNC):
We store LNG in essentially what is just a large Thermos bottle. The tanks are not refrigerated in any way other than the other refrigeration supplied by the liquid within the tanks. The tanks are essentially a tank within a tank. They're insulated around a top and bottom, and there's no additional refrigeration needed. One of the benefits of liquefying natural gas is that it makes it essentially portable. Methane, or natural gas, in its natural state as a gas, must be delivered via connected pipeline from Point A to Point B. However, as a liquid, LNG can be delivered by a truck, rail, or even shipping.

Close up of flowers
being dipped in LNG

NARRATOR (MUSIC and NAT SOUND under):
Another advantage of a liquefied gas is its extremely low temperature. How cold is it?

DS in lab

DON SHOWALTER (SYNC):
In this container I have an element that we're all familiar with, but most of the time as a gas, nitrogen, only this is liquid nitrogen. In here, a couple racquet balls. Notice how they bounce very well. Now, what will happen to those balls as I put it in that liquid nitrogen? Now, this liquid nitrogen is at a temperature of minus-196 degrees Celsius. So the temperature inside there now is some 225 or so degrees below room temperature. So that ought to change the properties of those balls that are inside there quite a bit. Well I think the balls have been in there long enough now. Let's see what happens. I'll put these gloves on, because that liquid nitrogen is very cold. I don't want to burn my fingers. Alright, I am gonna take one ball out and I'll set it right here and let that one alone. And I'll take the other one out. And just to show you what this liquid nitrogen has done, because it is so very cold, I'm gonna take that ball and hit it with this hammer. Here we go. (cont.)

DON SHOWALTER cont:
The ball shatters. So we see now that there has been a tremendous change in the properties of that particular ball because of this low temperature. Alright now here's the other ball -- it's warmed up so now so that I don't need that glove anymore. Look it's back to normal. So this fast freezing process even with something as cold as liquid nitrogen really doesn't harm the material. It certainly changes the properties immediately like this ball that we shattered, but after a while when it warms up, it's back to normal.

Close up of flower being crushed

NARRATOR (NAT SOUND under):
Liquid nitrogen also has many practical uses.

MONTAGE: Packages of food

NARRATOR (MUSIC and NAT SOUND under):
We take fresh food at the grocery store for granted. Its delivery depends on trucks that use liquid nitrogen for refrigeration, cooling the food without freezing it. Other foods are packaged and flash-frozen using liquid nitrogen.

Chemist working
in lab

NARRATOR (MUSIC and NAT SOUND under):
And biochemical researchers continue to develop cryogenic techniques for freezing living tissue without damaging it. This work will make it possible to store whole organs for indefinite periods.

RH next to Potomac River

ROALD HOFFMANN (SYNC):
We see now how matter can change from a gas to a liquid. In the process, energy is admitted in the form of heat. Something has to be taken away, and this is why we cool a gas, in order to liquefy it. The reverse process is that of heating a liquid in order to make it go into the gaseous state. These energy changes are crucial, and they're also part of our everyday experience. For instance, we can understand now how it is that we cool off when we sweat or when someone puts a wet cloth on the brow of a feverish person. What happens is that water liquid evaporates, goes to water gas. In order to accomplish that, heat has to be supplied to the liquid water. That heat must come from somewhere. It comes from my skin. That is why my skin feels cooled off when I sweat. (cont.)

ROALD HOFFMANN cont:
These energy changes that we have been discussing, in the observable macroscopic world of gases, liquids, and solids, must find their origin, their causes, in the microscopic world of atoms and molecules. Let's take a look at one particular substance as it moves through the three states of matter.

DS in lab

DON SHOWALTER (SYNC):
What you're looking at is a closed container of bromine. See the bromine liquid here, red, dark-brown liquid, and the bromine gas filling the rest of the vessel, a red-brown gas. I'm going to make use of this liquid nitrogen again. Remember, it's very cold, minus-196 degrees Celsius. To lower this vessel so that the finger in the vat gets into the liquid nitrogen. Now, what will happen if that temperature is, that bromine should change state, so the gas should go into the liquid, and the liquid should go into the solid. So we see all three phases, all three states of matter in action. Now, let's wait a little bit and see what happens now while that flask cools down. At this stage now we can see all three states of matter. This is the bromine gas, the top part up here. The dark material now is the bromine liquid, and at the very bottom is the yellow solid of bromine. All three states of matter. (cont.)

DON SHOWALTER cont:
We know that as we go from the gas and decrease the temperature, we go to a liquid, we decrease the temperature further, we go to the solid.

GRAPHIC: Kinetic energy and change of state

NARRATOR (MUSIC under):
On the submicroscopic level, the bromine particles in the gaseous state are moving quickly and chaotically. As the temperature decreases, the particles slow down until the attractive forces between them overcome the randomizing forces of kinetic energy. When these two forces reach a balance, the particles begin to stick together in clumps. When the clumps become large enough, gravity pulls them down to the bottom of the container. Now the particles are in relatively close contact. Attractive forces are holding them together, but they are still moving. As the liquid becomes colder, the particles lose even more kinetic energy. This results in another change of state. The liquid becomes a solid. Now the attractive forces hold the particles in a regular and ordered form that extends in three dimensions.

MONTAGE: Crystals

NARRATOR (MUSIC under):
Crystals are one of the most beautiful examples of this ordered arrangement of particles. Although they look like they were fashioned with a sculptor's skill, these formations are completely natural. They come from one of the most extensive collections of rare crystals in the world. Housed in the vaults of the Smithsonian Museum, many are too delicate for public display. What gives crystals their unique appearance? Dan Appleman is a geologist at the Smithsonian.

INTERVIEW: Dan Appleman, Smithsonian Geologist

SUPER: Dan Appleman

DAN APPLEMAN (SYNC):
A crystal is a particular kind of matter in which the chemical elements, which compose all kinds of matter, are very highly organized. They are not just organized, but they are organized into a very orderly array, like a column of soldiers. An extremely ordered form of matter is what we see when we look at a crystal. What this means is that, within a crystal, the chemical elements are arranged in a particular way to form a building block. Now, you can think of the building block as being like a, like a brick in a brick wall. (cont.)

DAN APPLEMAN cont:
And these building blocks within a crystal then are stacked in a very regular arrangement, in three dimensions, just like the bricks are stacked in a wall.

MONTAGE: Crystals

NARRATOR (MUSIC under):
And in crystals, unlike other forms of matter, you can sometimes see the shape of these submicroscopic building blocks with the naked eye. If the conditions are right, the external shape of the crystal is the same as the shape of the particles that make it up. Because of this, crystals provided one of the first clues to the fundamental nature of solid matter.

INTERVIEW: Dan Appleman (cont.)

DAN APPLEMAN (SYNC):
Way back in the 16th Century, the famous Danish naturalist, Nils Stenson, observed that wherever a crystal of quartz, such as this, was found, the angles between the faces were always the same. They weren't just random faces. They always had the same angles between them. And, in fact, quartz from anywhere in the world, from Hot Springs, Arkansas, like this huge slab, or from Brazil, like these beautiful amethysts, it doesn't matter where the quartz comes from, what color it is, what shape the crystals are, the angles between their faces are always the same.

MONTAGE: Crystals

NARRATOR (MUSIC under):
Infinitely repeating patterns of chemical elements, the invisible world of fundamental particles laid bare through the external beauty of these shapes. In crystals, we can also see how particles in a solid are arranged to create strength.

INTERVIEW: Dan Appleman (cont.)

DAN APPLEMAN (SYNC):
This is different from other forms of matter. For example, in a gas, the chemical elements are only very loosely and weakly organized, if at all, and they have very little relationship one to the other, which is why a gas can expand to fill any volume that one wishes. In a liquid, the chemical elements are a little bit more organized. There is an attraction between the elements, and so a liquid has a volume to it. But it will flow and fill any shape volume that you want to pour it into, because it does not have any rigidity at all. But it is more organized than a gas. A crystal is far more organized than a liquid. A crystal has a rigid shape which will not change, because the chemical elements that form the crystal have a rigid arrangement with respect to each other, which does not deviate.

MONTAGE: Crystals

NARRATOR (MUSIC under):
Strong and rigid, but elegant and fascinating, crystals take many forms. From gemstones like the Hope Diamond, the largest blue diamond known in existence to natural specimens of all shapes and colors, crystals exert a grip upon both our imagination and our scientific curiosity.

INTERVIEW: Dan Appleman (cont.)

DAN APPLEMAN (SYNC/VO):
I think the most fascinating thing about crystals, at least from the standpoint of a scientist that wants to study matter, is the unique insight that a crystal gives you into the nature of matter itself, into the way that chemical elements behave toward each other. It's very hard to do this in a form of matter such as a gas, or a liquid, where the chemical elements don't really have much to do with each other.

MONTAGE: Crystals

But in a crystal, the intimate association of the elements tells you a lot about the nature of the chemical elements themselves, just like an intimate association between people will tell you a lot about individuals. And so I find crystals especially fascinating because they tell us so much about the nature of the chemical elements themselves.

SUPER: A MATTER
OF STATE

MONTAGE: Nature shots, program graphics, program demonstrations, LNG plant, LNG trucks, crystals

NARRATOR (MUSIC under):
To review: Matter can occupy three different states: gas, liquid, and solid. Changes of state depend on the motion of submicroscopic particles. The motion of these particles depends on energy. Cooling particles takes away energy and slows them down. Heating particles adds energy and speeds them up. In a gas, these particles move quickly and randomly, they have no set volume or shape. In a liquid, the particles slow down and clump together. We use gases, such as natural gas, in many important ways. Cooling a gas into a liquid decreases its volume dramatically. This makes it possible to store and transport it more efficiently. In a solid, particles of matter have a definite volume and shape. They are held in a pattern that repeats itself in three dimensions. Crystals are a highly ordered form of solid matter. They were one of the first clues to the arrangement of particles in the solid state.

RH next to Potomac River

ROALD HOFFMANN (SYNC):
The states of matter are few, but the ways in which they are realized, the number of different substances around us, are many. Let me give you an example. I'm breathing oxygen, the life-giver, and that's obviously a gas. But here is another element, sulfur, that's chemically very closely related to oxygen, and yet it's obviously different, it's a solid at room temperature. Now, there are, obviously, different forces at work between the atoms or molecules of sulfur and oxygen within these two substances. We want to know why that is so. We have to probe deeper; we have to then ask what is the nature of the atom, what is it that makes an oxygen and a sulfur similar, or different? We will begin to look at this in the next program.

Credits, Closing Montage, Closing Music

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